Adaptive Bike Pedals

4600: 497-001

Honors Project Advisor: Dr. Scott Sawyer

Readers: Dr. Ajay Mahajan and Dr. Alper Buldum

By: Robert Csaky and Norman Hansen

Table Of Contents

Milestones

- Meeting with the physical therapist and engineering mentor - Nov. 5th, 2019
- Develop requirements needed to satisfy the customer-Nov 15th, 2019
- Brainstorm ideas to meet the requirements- Nov 22, 2019-Jan. 17th, 2020
- Coming up with a few rough designs for an attachment -Jan 24th-Feb. 7th, 2020
- Design review I- with PT and engineering mentor again to determine if requirements are met- Feb. 14th, 2020
- Check to see if there are any new requirements- Feb 28, 2020
- Make changes to the design as needed-March 14th, 2020
- Design review II- make adjustments to the design if needed to meet the requirements-TBD
- Manufacture by 3-D printing and assemble the product-TBD
- Test design in different scenarios-TBD
- Finalize design-TBD

Introduction

As a requirement of the University of Akron's Honors College and College of Engineering, every student participates in a capstone project. This project takes place over the Fall and Spring semesters of senior year. This project may be completed in association with Professors, design teams, or done individually. Our capstone is in association with the Biomedical Engineering Design Team at the University of Akron. The project title is " Adaptive Bike Pedal" which is to deliver an adaptive tricycle pedal for Safety Town. This will allow them to include more children in their summer program. The project stages include an abstract, conceptual design, and an embodiment design. Each part has an important role in developing a product. The abstract is to help build background and context for how pedals create motion and forces that are put through it. The conceptual design contains the building blocks and brainstorming to come up with as many solutions as possible. These solutions are then boiled down with different methods learned in "Concepts of Design" to resolve into a single design. This design is then realized in the embodiment design where it is 3-D modeled in computer software. This begins the manufacturing and testing for the product and iterations of the design are made as improvements come about. The final stage yields a product that has gone through all these steps and the input of knowledge the students have implemented from their past curriculum.

Abstract

The Adaptive Bike Pedals project is set out to create a pedal attachment device for a tricycle for our customer Safety Town. Their goal for this project is to serve children with low mobility in their legs and allowing them to be able to ride a bike. The need for this attachment is common in rehabilitation and physical therapy centers to help patients keep their feet on pedals. It also provides children inclusion with the other children when they are riding bikes. They can also be used down the road in homes of families that have children with disabilities, diseases, or disorders that inhibit them from keeping their feet on the pedals. There are attachments on the market already, but the problem with those models are they are costly and made for specific pedals. The goal to accomplish this project is to create an attachment that is lower in price and adaptable to different pedals that still offers the ability to be adjusted. The new attachment will be bolted into the frame of the pedal to secure it. It will have slots that act as a pathway for the bolts to move in. The slots will help the product adapt to many different shapes of tricycle pedals. To start the research there are questions that are brought up to point the research in the correct direction. They are as follows. How can the comfort of the product be improved? Should it be lighter or heavier? Can the straps form into a different shape over the foot? How will it be manufactured? The objectives for the project consist of having a prototype design review by the end of January and have a product ready by April. All of this will be accomplished by working with the team members, a seasoned engineer, a physical therapist, and one of the coordinators for safety town. The motivations for this work came from a desire to create something that would help an individual in their everyday life. The benefits of this work, if successful, could lead to creating personalized attachments for individuals, potentially entering the market and selling the

product, and opening new doors for the design team. The system will be measured based on how well the product meets customer needs as well as their satisfaction. The evaluation will include ease of installation, performance on the tricycle pedal, and the ability of the customer to ride the vehicle while maintaining their feet on the pedals. Finally, longevity and how adaptable the design is to other users will be evaluated. There will be a written report describing this whole process in great depth with all the iterations included. It will describe how problems were solved that run into and how decisions were made as a group. This report and design presentation will be presented when seniors present their projects in the spring. It will cater to an audience of the general public, so that everyone can understand what the project is, how problems were solved, and the outcomes of it all. The project will encourage communication and cooperative learning within the team. This project also provided the opportunity to work with underclassmen to teach them different skills learned through co-op experiences as well as introduce them to theory they may learn later on in their undergraduate careers. There are not many chances in classes to work together on design projects with aspects of communication, design, and theory mixed in. The team will need to be unified in order to get the project done efficiently and effectively. The project will require us to improve skills that will help us become well-rounded engineers such as time management, using personal strengths and understanding weaknesses. The initial design process will start with the ideating of new designs with the team. Designs will be organized and categorized based on the strength of the structure, ease of manufacturability, the complexity of the design, and if it meets the goals. Then create rough sketches and lay out some design parameters to consider before 3-D modeling. The next step would be to design these models in Solidworks, create drawings, and bring them back to the group to see if the design meets all of our customers specifications. Then analyze which manufacturing method is best. Then take the model to additive manufacturing and test fitment on an actual bike. Next, look at the design and see if improvements can be made with more iterations. After this, the final stages would be material selection and parts. To do this specifications of an assortment of materials are researched ranging from plastics and polymers to metals and determine which would be best based on cost, usability, and overall durability which can be determined from research. The first phase of iterations and testing will be done by the middle of April. Then take the product to the customer for feedback and see what can be changed in iterations to come. Continuing this process at the end of April with the goal of having a final design by then. Then look into the manufacturing and materials and have them manufactured by the end of April. All of this will be done while staying under a budget. A sum of $200 was granted from the BME design team to help with some of the costs. Most of this budget will not be used until the final stages of the project. It may have to use some of it for higher quality additive manufacturing and parts for the pedals. It is important to keep this boundary in mind through all of the design processes.

Conceptual Design

This problem from the surface seems like a design problem with the highlight of the design being the adapted pedal. The problem becomes more complex when how the user interacts with it is realized. There are complex kinematics that go through a pedal from how the user interacts with the pedal, to how it captures the foot, the axis of rotation, how the pedal interfaces with the bike itself.. The complexity of motion can be seen in Figure 1.

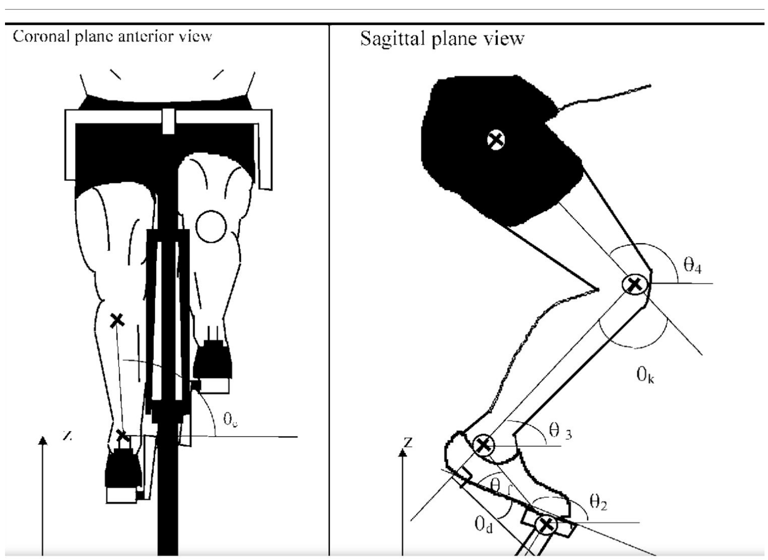

Figure 1: Kinematics of a Cyclist (Bailey, 2011)

The theory for much of this project is biomechanics and how the kinematics of the bike are changed when the bike is adapted. Jane is the physical therapist that works with children who have disabilities and advised the team greatly in the area of biomechanics as well as things to look out for when designing things for people with disabilities. She is a mentor of the Biomedical Engineering Design Team at The University of Akron and she has helped greatly in this project. The first area to be studied is how the human body moves while on a bicycle and what the important points of contact are from the bike to the rider. The position being studied for this scenario will be the standard upright seated position as seen in Figure 2.

Figure 2: Upright Rider on an Adapted Tricycle

Figure 2 is an image of the first iteration of the Adaptive Bike Pedal project. The pedal was used for a disabled patient who had trouble keeping his feet on the bike pedals. His family reached out to the University of Akron and the Biomedical Engineering Design Team took on the challenge. Some ideas and information was improved from this model and used in the design of the pedal for Safety Town. The focus can then be pulled to the leg and foot and how those areas interact with each other as forces are applied to each other as well as what happens externally on the bike. This is an important area of study as it will drive the rest of the conceptual design. Figure 3 shows the motion of the foot in regards to it being secured in place of the pedal and the motion being considered which will be another parameter for this project. The foot is rotating and in turn produces forces and moments. Much of the pedal motion is downward and the geometry of the bike cranks causes rotation and as seen in Figure 3, the pedals are offset 180 degrees from each other so that one foot is always forcing down.

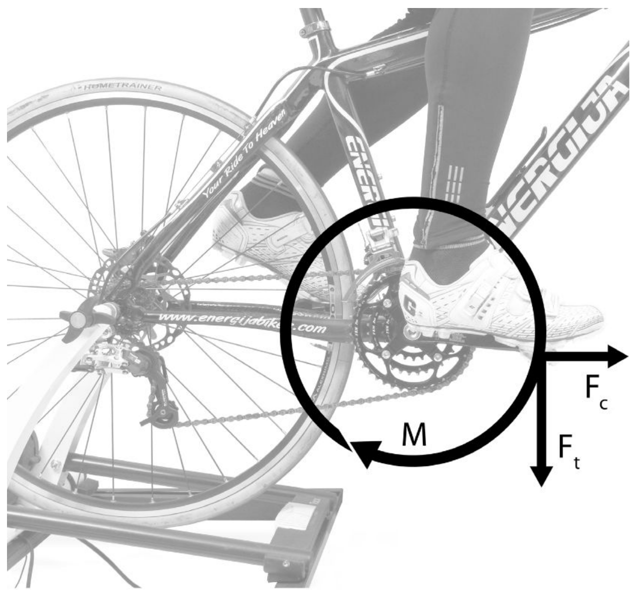

Figure 3: Graphic of Pedal Kinematics (Fonda, Nejc, 2010)

This force is then transmitted through the crank arm which is connected to the bike via the bottom bracket. The forces are then dispersed throughout the frame of the bike to dampen as well as allow the bike to move as the chain needs a solid point to rotate around. For the adaptive pedal concept, the main forces being considered will be that of the foot, the pedal below it is attached to, and those from external impacts. Next, the customers needs will be looked at for context into the overall footprint, timeline and budget of the build. These can be seen in Figure 4 with some timeline notes as well. The notes on the whiteboard were the skeleton of the project and the goal for the team was to organize and whittle these notes down until a solution is in sight. This is done using many concepts from the class “Concepts of Design” where many tools will make this process easier.

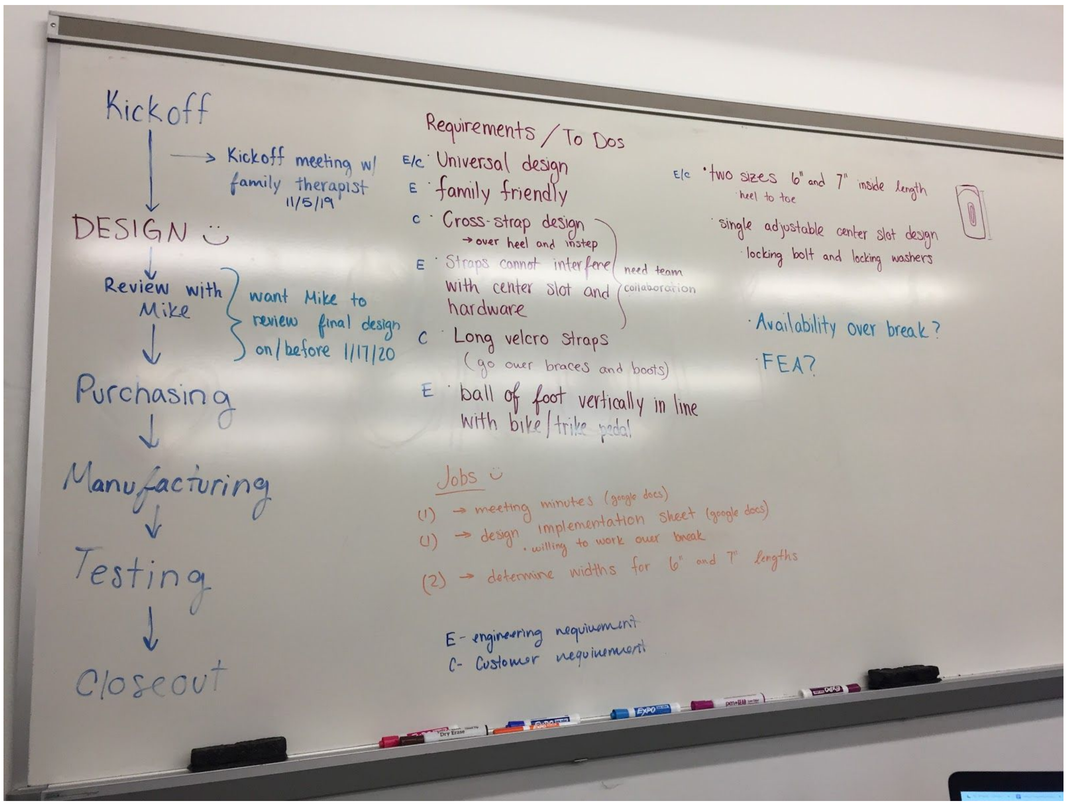

Figure 4: Initial Planning with the Customer

The customer needs a bike pedal that can be adapted to their fleet of bikes so that any of the patrons have the ability to ride their bikes. Their patrons consist of children between the ages of five and seven years old. This is helpful for understanding the length, width, and durability requirements of the adaptive pedal. The customer also requested the foot be secured using straps and be easy to place feet into as well as remove. There were also some requests made about the pedal in the sorts of design which will be addressed later on such as a heel stop and an overall design aesthetic that was inclusive and appealing. A concept map was created to propel ideation and help bring ideas to the table. The concept map can be seen in Figure 5.

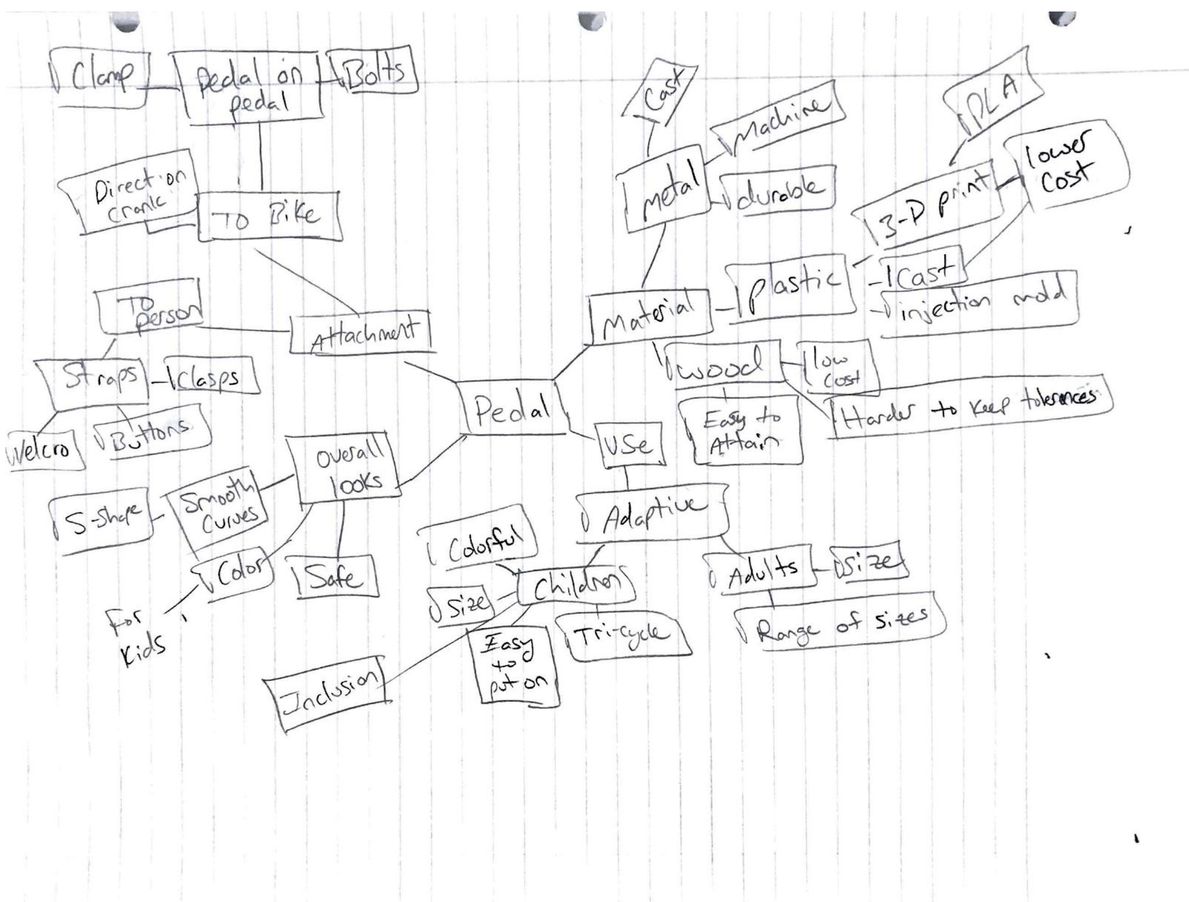

Figure 5: Concept Map for the Bike Pedal

This map allows for a birds eye view of the project that is being undertaken. It can show problems that may arise early down the road and those can be dealt with as needed. For this situation this map allowed us to explore more possibilities as well as ask focused questions to the customer to receive better feedback and create a design in a more efficient manner. This method was taught in "Concepts of Design" along with a method called a morphological chart (Dieter & Schmidt, 2013). This chart is helpful to follow up after the Concept map to brainstorm the functions of the product as well as how they will be carried out. Figure 6 is part of the morphological chart.

Function						
Adjustment to Bike	Strap	Fasteners	Friction for Footbed	Attachment	Material	Foot location
Slot	Velcro	Screws	Sandpaper	To Crank Arm	Aluminum	Heel Stop
Oversized Holes	Clasps	Nuts and Bolts	Rubber	To pedal	Steel	Toe Stop
Clamp	Buttons	Glue	Modeled in features		Plastic	Straps
No adjustment		Epoxy	Grip Tape		Wood	

Figure 6: Morphological Chart for the Pedal

The morphological chart shows the different functions of the pedal and different ways that it can be done. These were then shown to the customer and with the ideas in mind the final concept was drawn up and approved. Before entering the embodiment design stage of this project the parts that needed modeling were decided upon with the use of a physical decomposition chart seen in Figure 7. This breakdown allowed the two designers to optimize who would model each part to optimize the embodiment design portion of the project. The figure below is the physical decomposition of the pedal into physical parts that will need designed, purchased and or made.

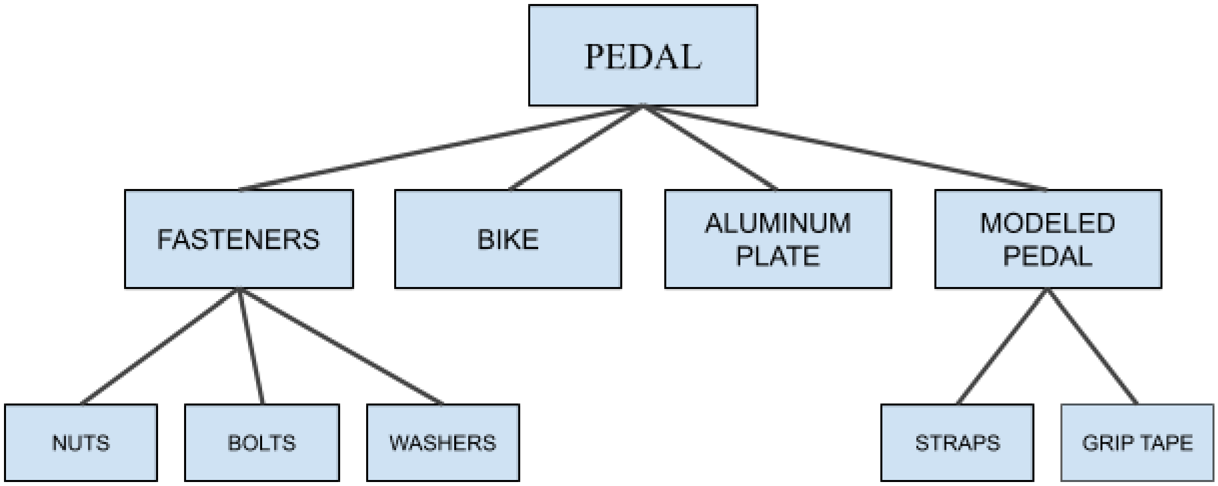

Figure 7: Physical Decomposition of Pedal

Figure 6 shows an example of all the physical pieces that will need to be in the three dimensional model as well as be purchased, manufactured and refined by the end. Now, with the brainstorming concluded and the conceptual design solidified the next step is to start the embodiment stage. To recall the embodiment stage is when the ideas are put down on a page and then modeled and then refined.

Embodiment and Detail Design

From the beginning, it was decided for the pedal to be 3-D printed. The main reason for this choice was because manufacturing the pedal would be much more costly than 3-D printing. Also, only a small amount of pedals were going to be needed by the customer. The two materials that were being considered were PLA and ABS. Both were readily available at the University, so the decision was based on material properties and characteristics needed for the final product. PLA is used when aesthetics are important and ABS is used when strength and ductility are important (Giang). A few factors went into choosing ABS as the material. One factor was that the customer was focused on function rather than aesthetics. Another factor is that there could be a respectable amount of force on the pedal. Considering the bikes would be used by young children, the force would not be much, but to be safe, ABS was chosen to avoid failure. Some benefits of choosing 3-D printing are that it is relatively cheap and that it is plenty strong for what the customer needs. The negatives of 3-D printing are that, generally, only one product can be made at a time and it takes a long time to produce one product. After weighing the positives against the negatives, it was decided to stay with the plan of 3-D printing the pedal.

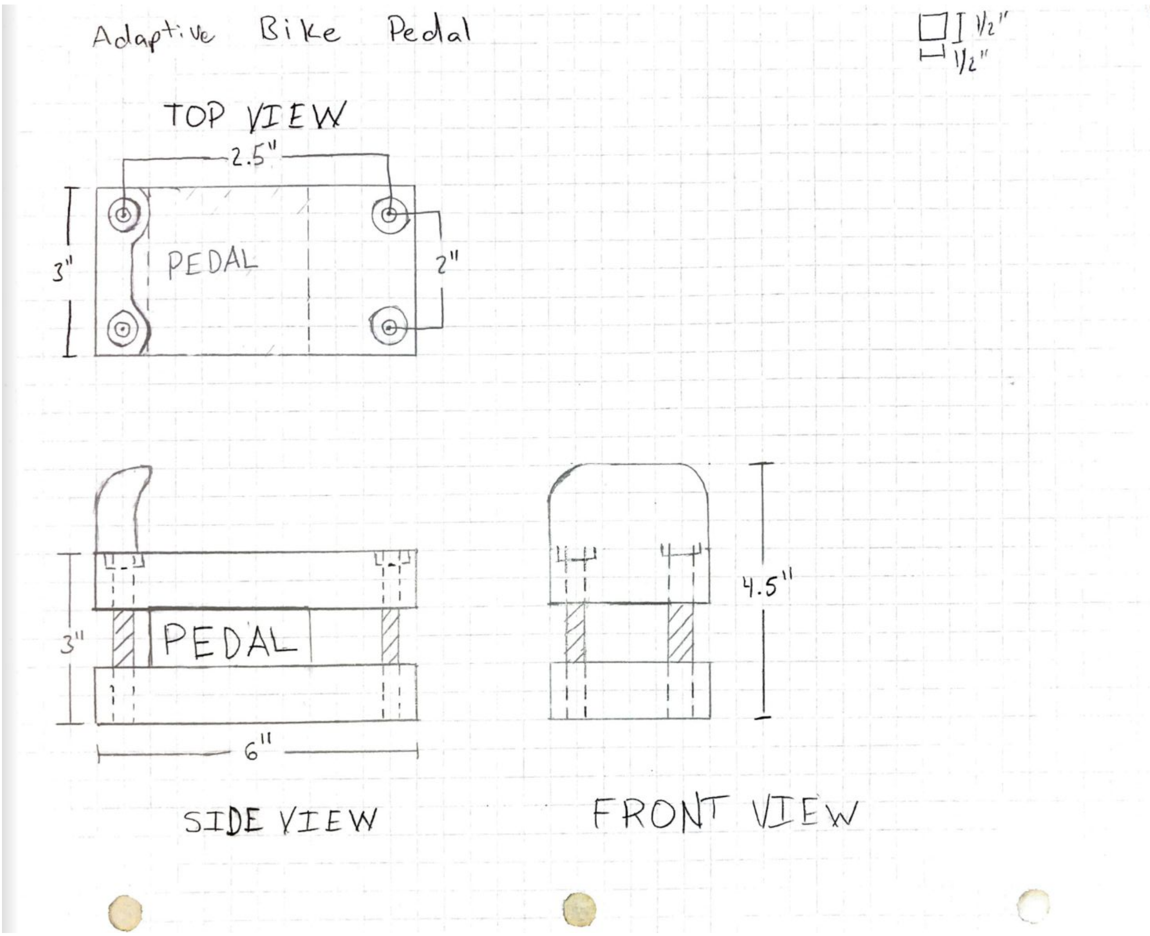

Figure 8: Early Embodiment Design

Figure 8 shows a drawing from the early stages of design. The pedal initially had four fastening points. Two embedded in the heel stop and two at the front corners of the pedal. It also had a rugged rectangular shape to it. This was changed in the final design to make the pedal more aesthetically pleasing to the eye and to avoid contact with the frame of the bike. At this stage, there was no plan for keeping the feet fastened to the pedal. Straps were used in the final design for this purpose.

Once the material was decided, the design process began. Using a previous model from a project last year, a template was made. Some ideas were taken from the old model, however, since the new pedal would be used on a completely different bike, it had to be re-designed.

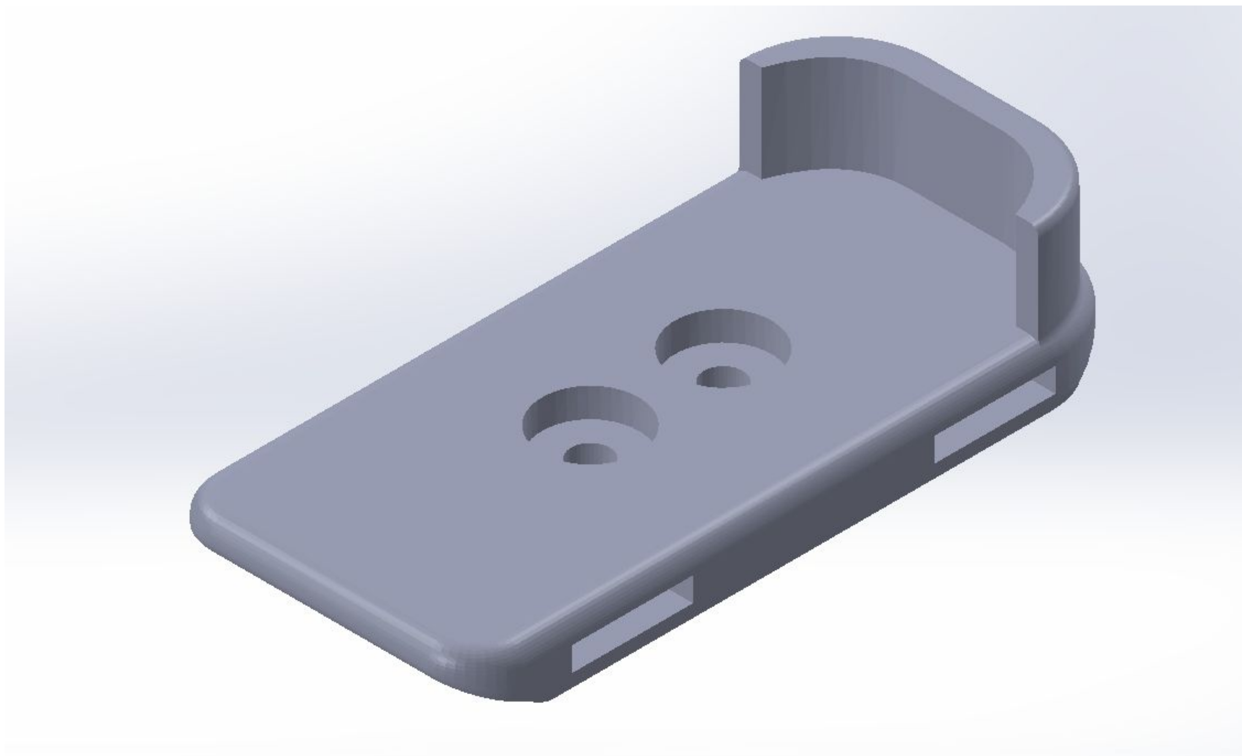

Figure 9: Early Version Clearance Hole Design

Figure 9 shows the earliest design for the pedal. The original idea was to have two holes for fasteners. This was decided with the hope that it would be able to fit on most pedals. The heel stop was curved to fit the heel of a shoe sufficiently. The slots for straps were designed as a front and rear strap. The front strap would wrap around the dorsal surface of the feet and the rear strap would wrap around the instep. The rectangular shape was thought to be best in order to have enough surface area to fit a patient's shoe on. The edges were round for aesthetic looks and to avoid any stress concentrations.

Once an initial design was made, it was time to meet with professionals to cater this product towards the needs of the customer. After meeting with the physical therapist and an engineering mentor, the needs were discussed and changes were made to the design. The physical therapist, Jane, had already worked with a patient that used adaptive bike pedals. From her experience, she was able to provide some concerns and ideas of ways to improve the design of a new attachment. The first design implementation was made to the heel support. Jane brought up a concern regarding the patients' heels being secure in the pedal. Taking this into consideration, the heel support was heightened by a half of an inch so the patients' heels would be secure. A second implementation was to the shape of the heel support. Jane brought up a request to move the heel support back to allow the foot of the patient to set all the way back in the pedal. The request was not able to be met as it was decided that it would not solve the problem. However, the shape of the heel support was changed to accommodate the issue. The heel support was rounded at the corners to allow the foot to sit nicely. A more aesthetically pleasing design was requested by the customer. Upon hearing this, the body of the pedal was changed to an hourglass shape. Changing the design to an hourglass shape also ensures that the pedal will not hit the bike frame as it rotates around its axis. The strap design was changed to a cross-strap design after listening to Jane's recommendation. She suggested a cross-strap design because a simple front and back strap design was uncomfortable for the patient in her past experience. The slots for the straps were rounded at the edges to lessen the stress on them.

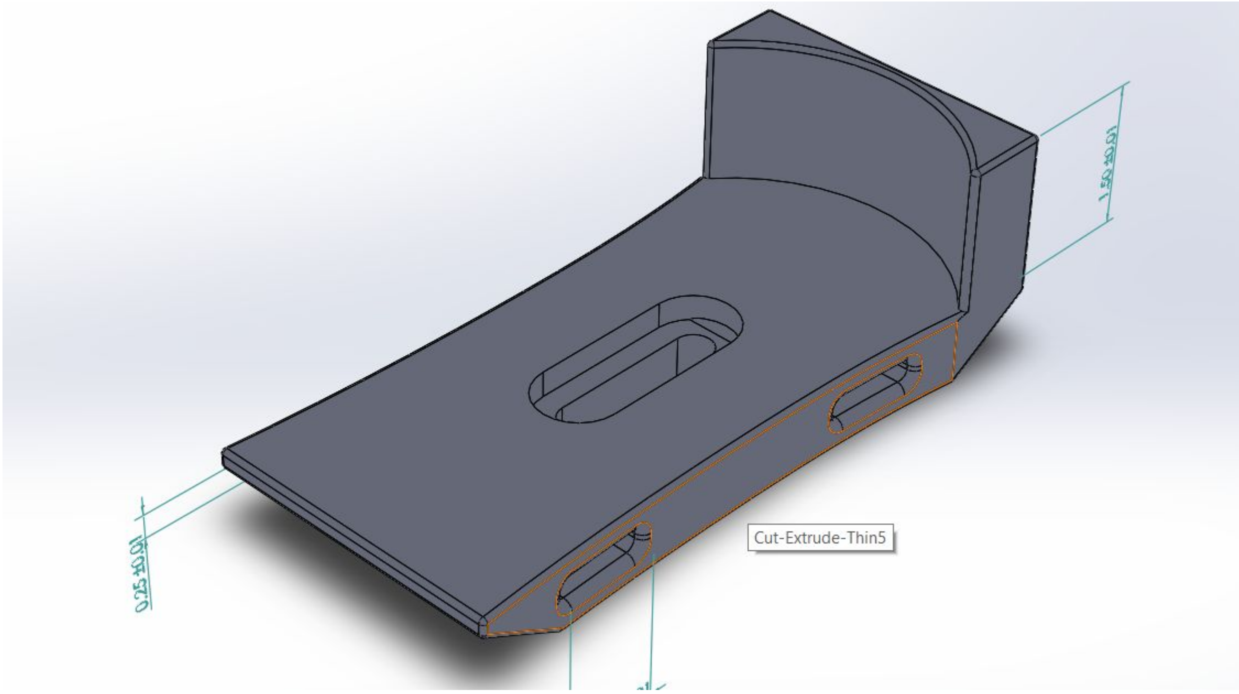

Figure 10: Early Version Slotted Design

Figure 10 shows a later version of the slotted design with all of the newly implemented designs. The purpose of the slot was so the pedal would be able to fit on varying styles of pedals. This was changed for the original two hole design due to varying bike pedal dimensions and positioning. A concern that Jane had about the straps was that the rear slots were positioned too far back on the adaptive pedal. Her concern stemmed from previous experience where the patient's ankles became irritated due to the straps being situated too far back on the instep. The holes for the slots were rounded at the edges to prevent any unneeded stress on the straps and allow them to wrap around the pedal more easily. The hourglass shape was implemented into this design to avoid contact with the bike frame. Figure 10 shows the rounded slots and the new positioning for the rear slots. The slots were also designed to go with the hourglass shape in order to make it easier to achieve a cross-strap design. The heel stop was raised and the corners were rounded to ensure a proper fit with the patient's heel.

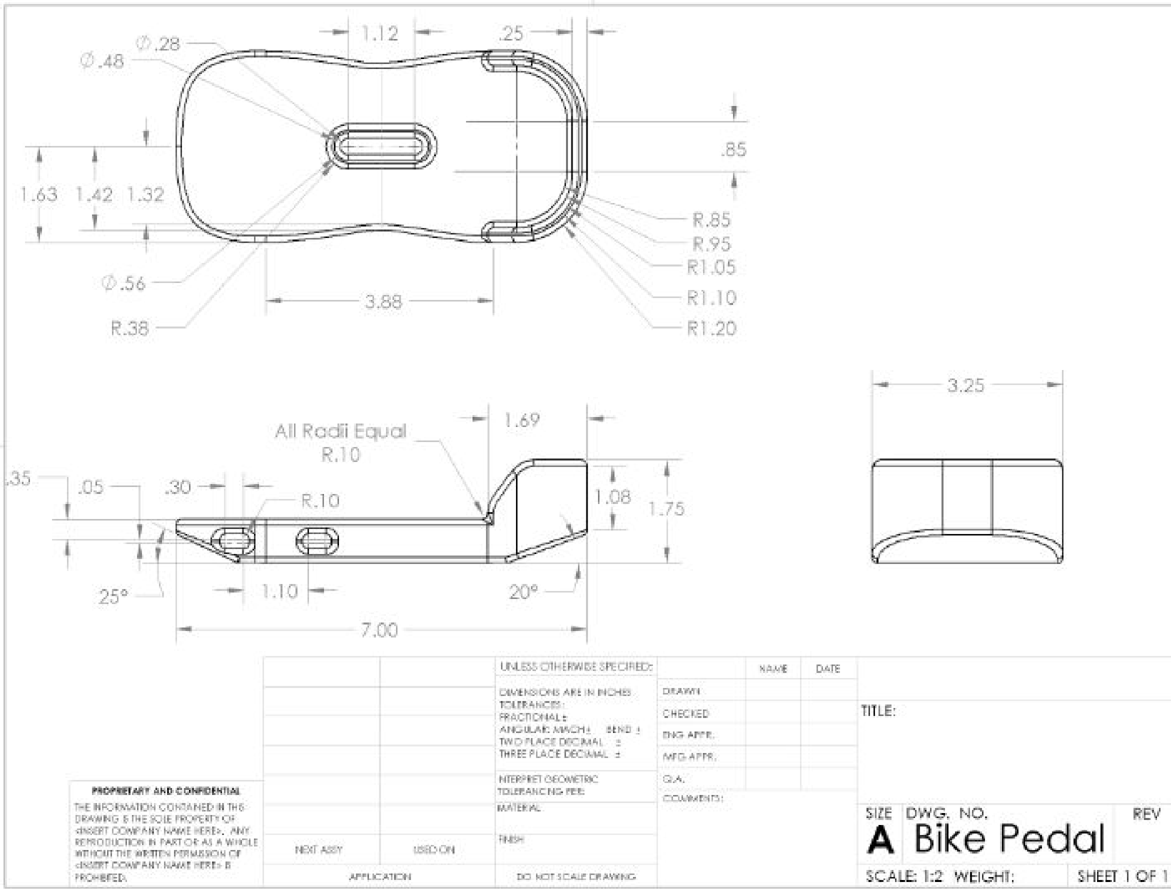

Figure 11: Drawing of The Final Design

Figure 11 shows the final design of the adaptive pedal. A few changes were made from the previous design. It was decided to remove the rear slot for the strap and place a second slot directly behind the front slot. A cross-strap design will be used to cover the dorsal surface of the foot. Secondly, the corners of the pedal were rounded to make it look more aesthetically pleasing and remove any stress concentrations to further prevent cracking. The hourglass shape was improved to create a better surface for the straps to wrap around the patient's foot.

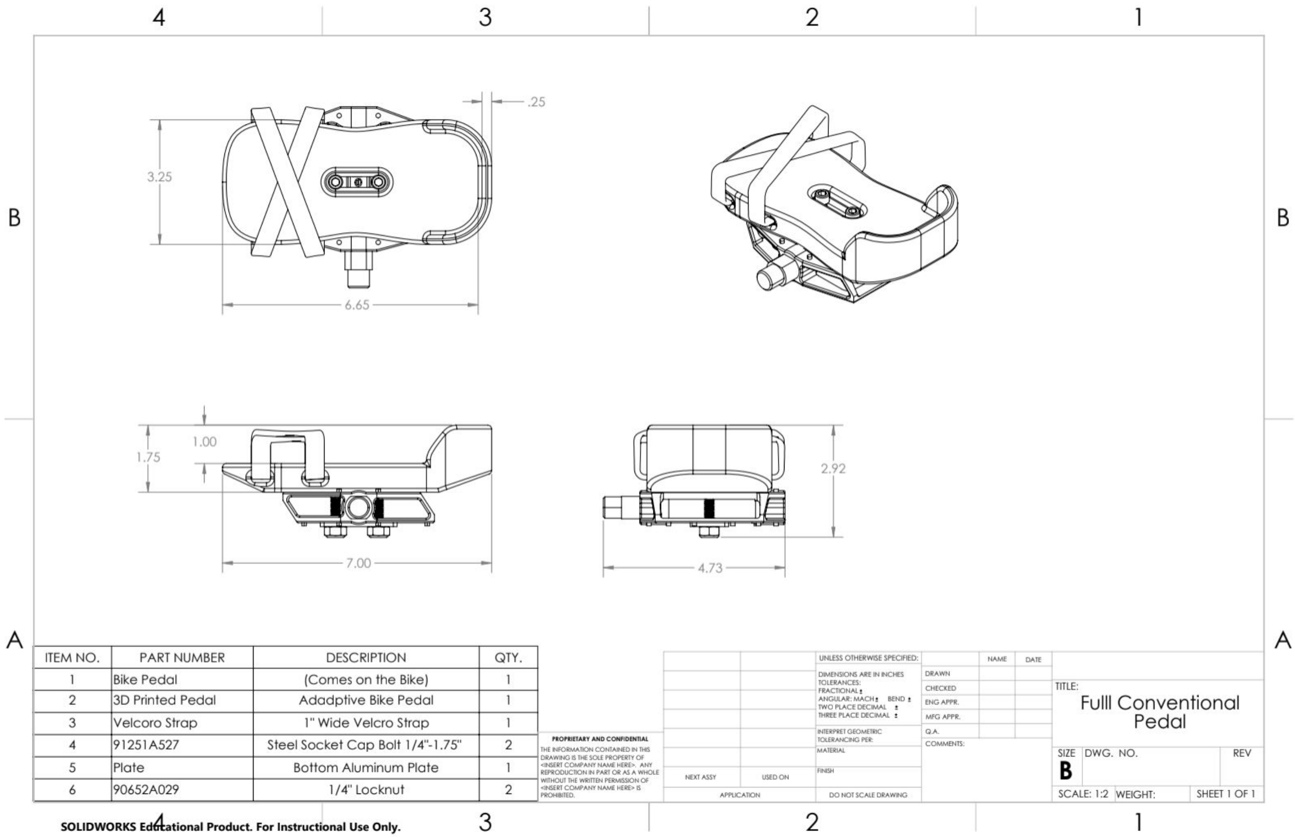

Figure 12: Drawing of Final Assembly

Figure 12 shows the drawing for the final assembly including how the adaptive pedal attaches to the bike pedal. The adaptive pedal is attached to the bike using a backing plate and two bolt/nut combinations. The bolts feed through the openings in the bike pedal. It also shows the bill of materials on the bottom left. Most of the parts are off the shelf for cost savings and availability. A rough cost analysis puts this pair of pedals under $40.00.

After these changes were made to the design, testing was discussed. Parameters were taken into account when coming up with what to test on the pedal. Strength was considered to be an important parameter to consider. Testing for strength would yield helpful information regarding the overall strength of the product and when it would break. Ways to test for strength would be impact, drop, and scratch tests. The shape was another parameter that was considered to be important. The shape of the pedal had to be designed a certain way so that it didn't hit the ground or the frame of the bike as it rotates as well as all sharp corners needed to be rounded to lessen the opportunities for cracks to form. Finally, some finite element analysis was going to be completed to learn about important stress concentrations in the structure of the pedal. Important areas to focus on for the FEA would be the fastening points and the locations of the straps.

Figure 13: Exploded view of final design with pedal

Figure 13 shows an exploded view of the final design. The exploded view also shows more clearly how the adaptive pedal fits the bike pedal. It shows the backing plate and the two bolt/nut combinations. The straps were included in the final 3-D model to show wear they secure the foot.

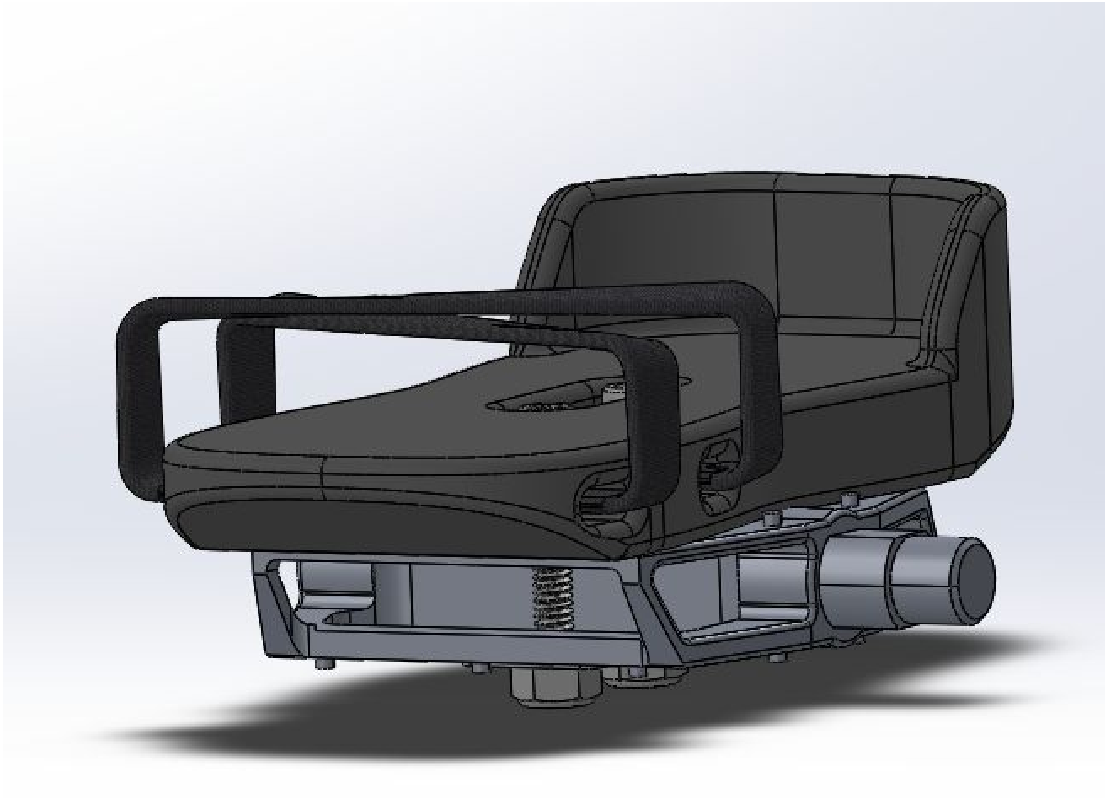

Figure 14: Isometric View of the Final Design

Finally, Figure 14 shows an isometric view of the full assembly. The bike pedal is included to show how the adaptive pedal attaches.

Discussion

Due to the campus closing, no tests were able to be carried out on the product. On March 16th, the plan was to pick up a bike that would be used for Safety Town and measure it to get final dimensions for the adaptive pedal. Once the measurements were taken, a final design would be created and taken to Jane to have a second design review. This design review would go over any final changes needed to be made before manufacturing. Once the design review was concluded and final changes were made to the pedal, the manufacturing process could begin. A 3-D printer from the University would be used to print the pedal. It would be printed using ABS and the positioning of the printing would be best starting from a flat surface on the pedal. The pedal was designed so that it would be printed in its normal upright position. In other words, the pedal would be printed from bottom to top. Once the pedal finished printing, it would be put through the tests discussed previously. After the tests, the design would be finalized and printed again. Delivery to Safety Town would be the final step. Feedback from Safety Town would be encouraged and taken into consideration when designing future pedals.

Conclusion

The Adaptive Bike Pedal project was set out to provide a solution for Safety Town to include disabled children in their program. The problem they were facing was that children with disabilities were not able to keep their feet on the pedals. Safety Town is supposed to be a fun and educational program for children to help them learn how to travel the streets safely. The Biomedical Engineering Design Team took on the challenge to provide a solution to Safety Town. After obtaining valuable advice from a physical therapist and an engineering mentor, a final 3-D printed pedal design was completed. The next steps in the process would be manufacturing the pedal and running tests to make sure it can hold up to the task. Once the tests are run and adjustments are made to the pedal, a final product will be produced. The team hopes that it will provide a solution to include all children so they can be well educated to travel safely on the street.

References

1. Fonda, Borut, and Nejc Sarabon. “Biomechanics of Cycling.” *Sport Science Review*, vol. 19, no. 1-2, Jan. 2010, doi:10.2478/v10237-011-0012-0.
2. Bailey, Martin, et al. “Kinematics of Cycling in Relation to Anterior Knee Pain and Patellar Tendinitis.” *Journal of Sports Sciences*, vol. 21, no. 8, 7 Feb. 2011, pp. 649–657., doi:10.1080/0264041031000102015.
3. Dieter, George E., and Linda C. Schmidt. *Engineering Design*. McGraw-Hill Education, 2013.
4. Giang, Ken. “PLA vs. ABS: What's the Difference?” *3D Hubs*, www.3Dhubs.com/knowledge-base/pla-vs-abs-whats-difference/.